# Update on the developments of the Supernet NL transmission cable project

March-21-2018

Rob Ross

# Contents

TenneT at a glance

Background of exploring HTS technology in the grid

Supernet NL

- Organization
- Location
- Planning
- Status

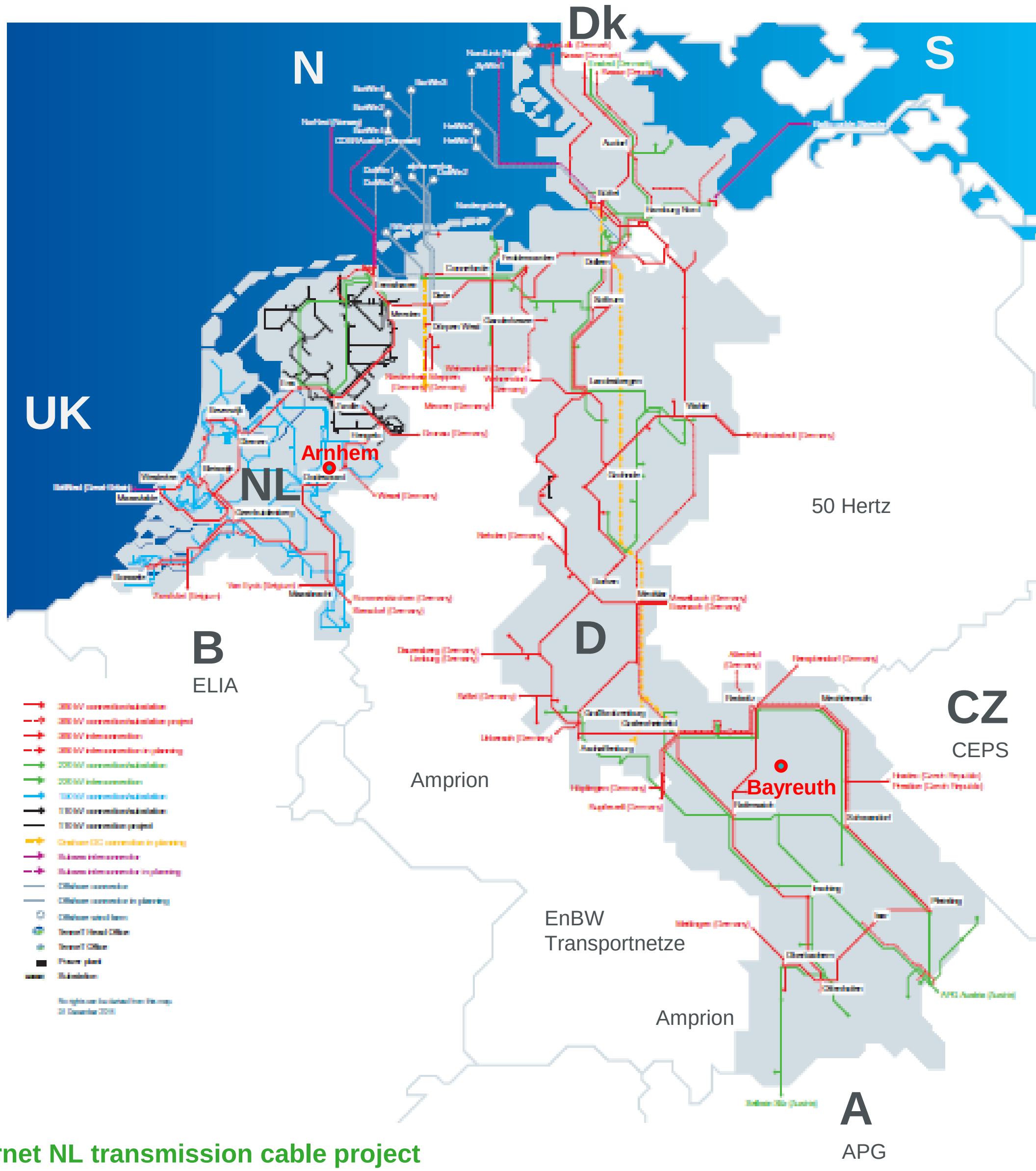
Considerations

- Accelerated testing
- Representative cable length
- System integrity →
- Reparability

# TenneT at a glance

## Cross border TSO in EU

- HQ in Arnhem and Bayreuth
- 41 Million end-users
- 22774 km HV lines & cables
- Security of supply: 99,9986%
- Robust and efficient grid
- Connected to 7 states in Europe



# Background of challenges

- Transmission large scale renewable energy:
  - Connecting off-shore wind D+NL >10.5 GW in 2023; >50% realized
- Limitations of XLPE-cables at extra high voltage (380 kV)
  - Mainly capacitive current; thermal impact; right-of-way claims
- Demand for undergrounding overhead lines in urban areas (150 kV)
- Demand for dramatically lower B-fields in urban areas (≤ 0.4 μT)
- Easy to integrate in urban soil crowded with infrastructures
- Outlook to underground 380 kV

<u>Boundary conditions</u>:

- **Larger current capacity**
- **No mutual thermal impact**
- **No external magnetic fields**
- **Easy to integrate in cities**
- **Cost effective and robust**

# Supernet NL

- Opportunity to qualify HTS technology in the TenneT transmission grid
- Tender procedure with restricted cost level as test of maturity
- Specification and guidance by knowledge organizations

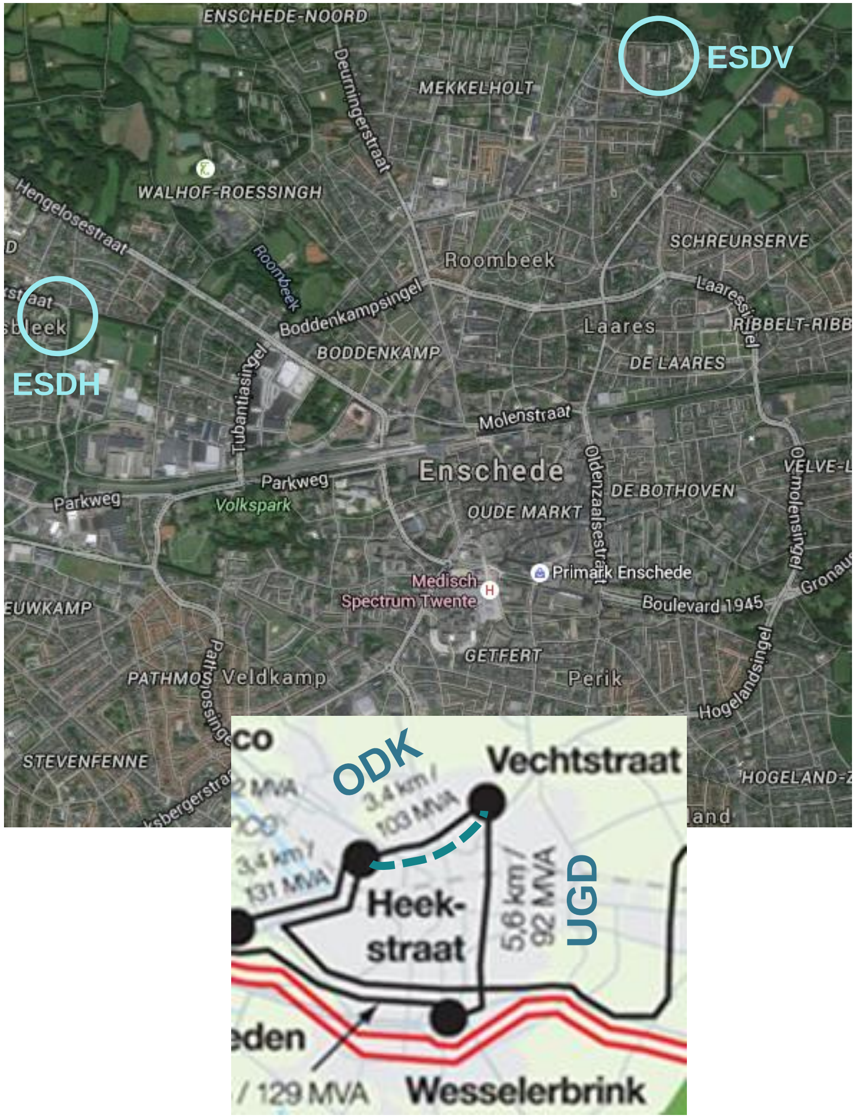
| WP | Leader | Subject |
|---|---|---|
| 1 | TenneT | Location & demands |
| 2 | TUD / UT | Demands electrical, magnetic and thermal control |
| 3 | IWO Project | Demands reliability, availability and reparability |
| 4 | HAN | Demands measure & control technology |
| 5 | TenneT | Specifications and tender |
| 6 | TenneT | Construct and install |
| 7 | TenneT | Demonstrate before actual commissioning in the grid |
| 0 | RH Marine | System integration aspects |

Sponsored by RvO
Agency of the NL Ministry of Economic Affairs

# Proposed location: Enschede

**Characteristics & status**:

- Circuit: ESDH-ESDV, 3.4 km long
- U: 64/110 kVrms, S: 150 MVA
- Planning: end of 2019 … hm
- Status Mrch.’18: tender evaluation & EB evaluation; consult MoE&C

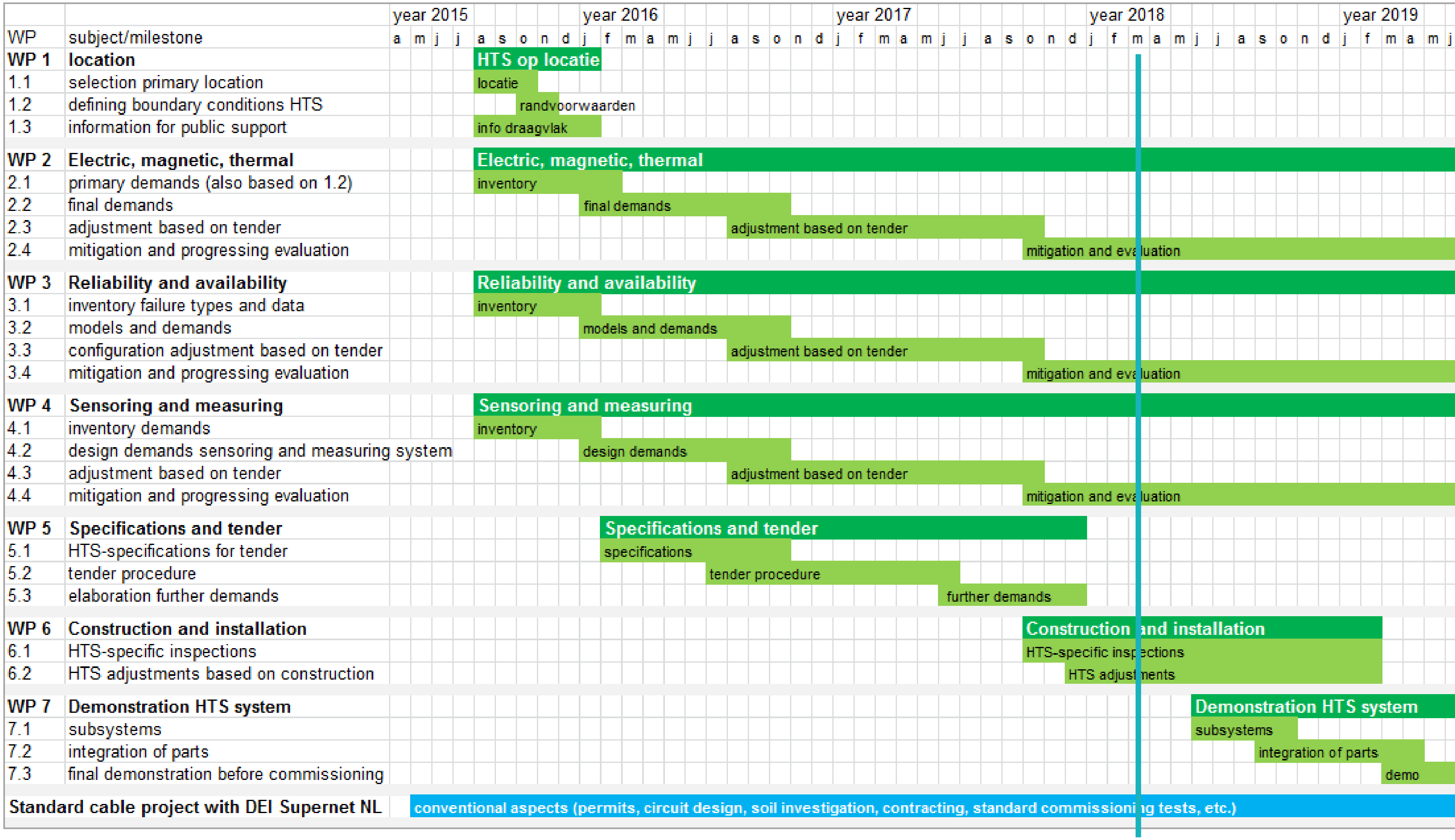



**Issues of particular interest**:

- Technical feasibility
- Cooling only from stations
- Cost efficiency
- Availability, reparability, repair time
- Increase cool down rate
- Quality evidence

# Planning Supernet NL

status




extension
required

# Status March 2018

## Demonstration project

- So far, HTS cable were scientific pilot projects
- Supernet NL cable must be able to work as ‘normal cable’
- Pressure on price in design, materials, production, integration
- Competition of 3 consortia world-wide

## Tender evaluation

- Price CAPEX, OPEX, TOTEX
- Dec.’18: Best and Final Offers
- Executive Board and Ministry of Economic Affairs & Climate Policy to decide

Sponsored by the Netherlands Ministry of Economic Affairs

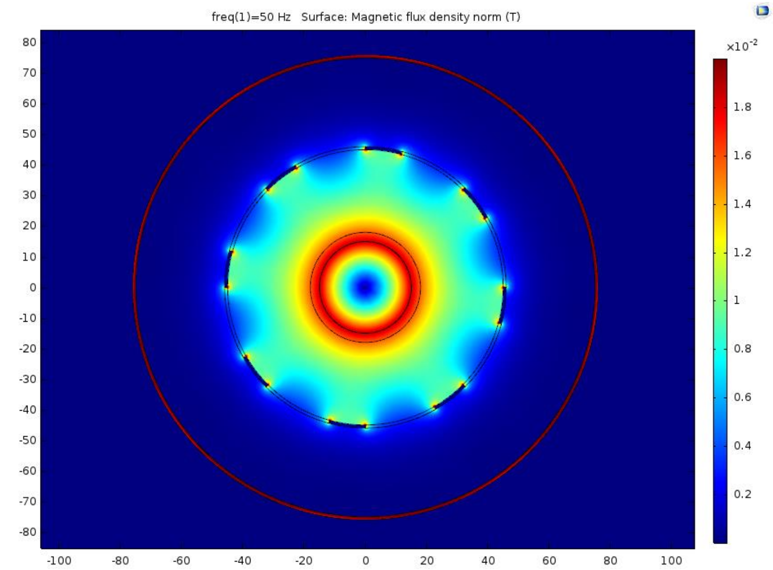
# Price and earth screen

Much tape goes into earth screen

Tape price in **€/Am**

Tempting: increase A/m$^2$

- Would make sense if less tape is required
- However 70% of tape goes into earth screen
- In Enschede even modest tape give too high current capacity on earth screen
- Question: do we need high A/m$^2$?
- Second grade tape might be blended in on earth screen




Some gap between tapes required
Magnetic field leaks
Adds to losses in shield and cryostat

# Accelerated ageing in testing

**Power law**

$$(E_{\text{test}})^p \times t_{\text{test}} = (E_0)^p t_0 = const.$$

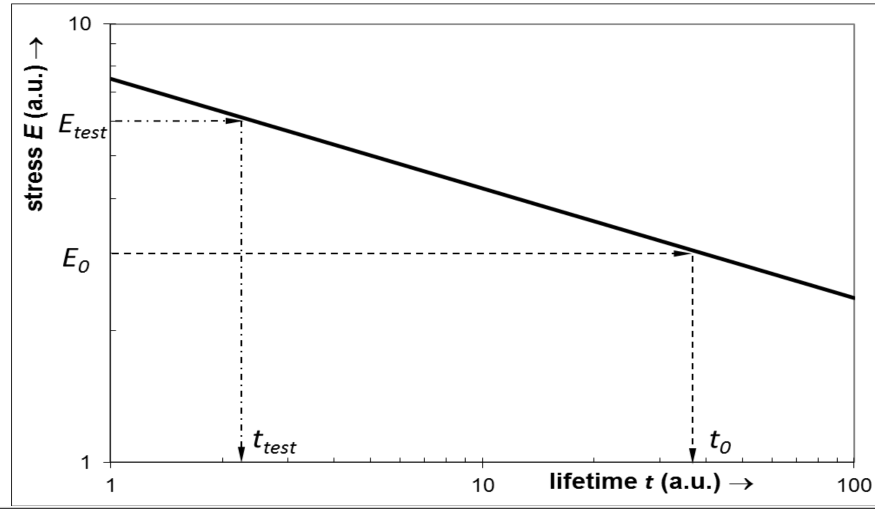
Extensively used

- Water treeing: $2 \le p \le 4$
- Partial-discharge ageing: $p \sim 4$
- Dry contaminants: $8 \le p \le 10$ ($p$~9)
- Pure polymer: $p \ge 15$
- <u>Based on very limited experience</u>
- What $p$ is realistic for HTS testing?

Stress $E$, ageing time $t$

Power $p$ (from ramped tests)

*1 hr test = $(E_{test}/E_0)^p$ hr at rated stress*




**Thermal acceleration**

$$t_{\text{remaining}} = A \cdot \exp(\Delta H / kT)$$

- Relevant at terminations
- Activation energy $\Delta H$
- $T$ temperature
- $k$ Boltzmann constant

| Cryogen | Dielectric Tape | HDPE (Valeron) | HDPE, PE | Polysulfone | Polypropylene | Polyimide (Kapton) | Aromatic Polyamide (Nomex) | Polyethylene terephthalate (Melinex) | Calendered PE paper | Poly(2,6-diphenyl-phenylene oxide) (Tenax) | Cryoflex (Southwire) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | LHe | 11 | 8 | 10.5 | 7 | | | | | | |
| | LN2 | | 17 | | | 11 | 100 | 14-18 | 22 | 80 | 26.2 |

\+ Other processes …?

# Representative testing length

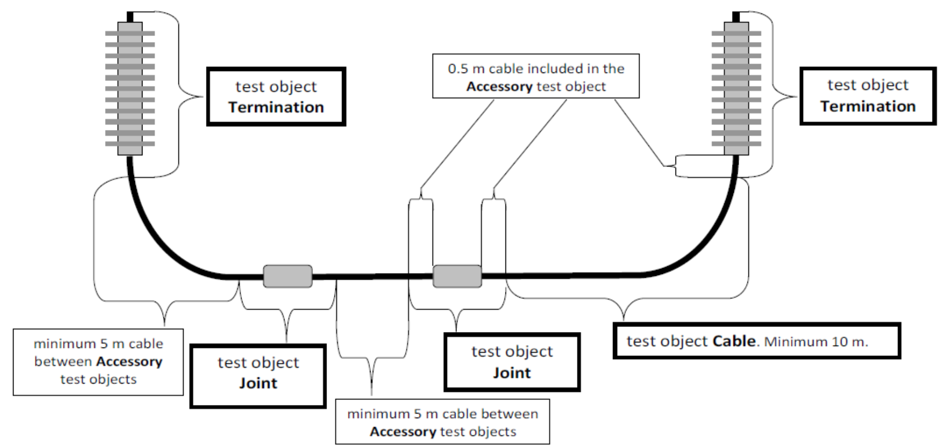
Tests work with fixed object length:

- ≥ 10m total test length
- ≥ 5m between accessories

Average *t* and scale parameter *α* scale with ageing object length

$$t_{0,\text{cable}} = t_{0,\text{sample}} \cdot \left( \frac{L_{\text{sample}}}{L_{\text{cable}}} \right)^{1/\beta}$$

***Example of test loop***




- The shorter a test length *L*, the longer it will survive!

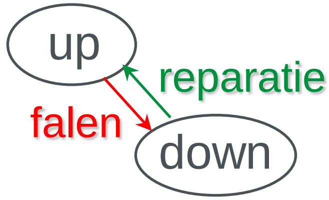
- 3.4 km / 10 m = 3400
- E.g. 2<$\beta$<4: 58<$t_{sample}/t_{cable}$<7.6

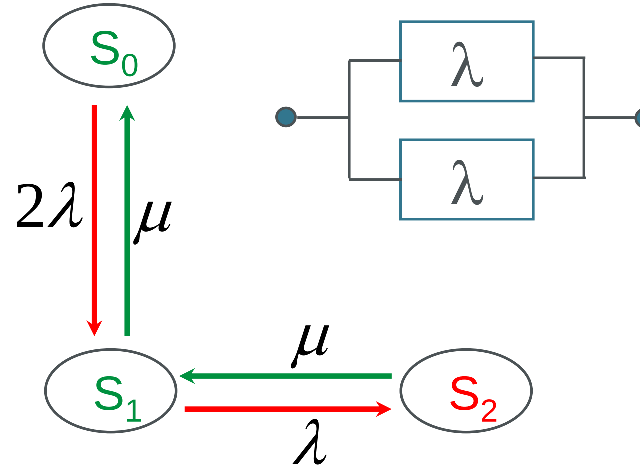
- Recommendation: Cigré TB 538
- Testing standard: IEC 60840

# System integrity

## Reliability

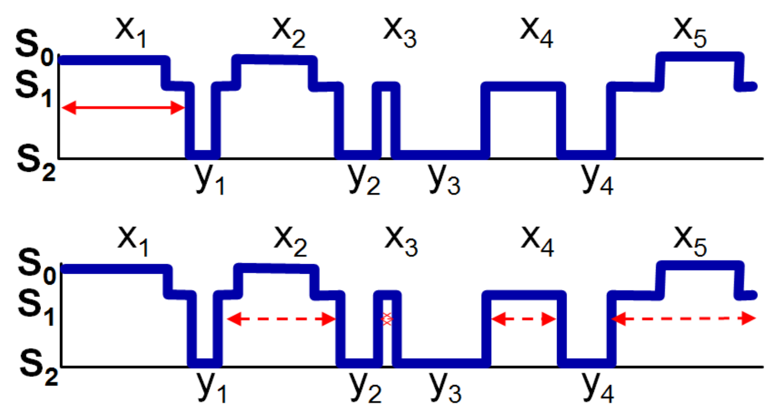
- Time to failure
- Remaining life




## Redundancy

- Parallel circuits
- System parts?


## Availability

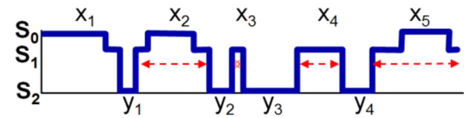
- Balance failure and repair rates
- Lower failure, increase repair rate

$$MTBF = \frac{\mu}{2\lambda^2} + \frac{1}{\lambda} = \frac{2\lambda + \mu}{2\lambda^2}$$

repair rate matters

$$A_\infty = \sum_{j,working} \pi_j = 1 - \sum_{j,failed} \pi_j$$

# Reparability issue




**Availability depends on**:

- MTBF mean time between failures
- Repair time

**Getting (back) into operation**:

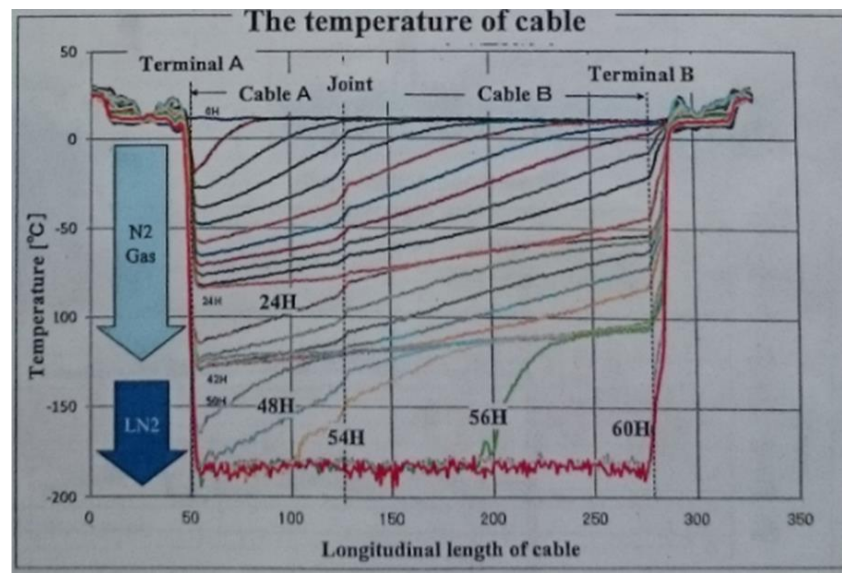
- Detect failure
- Localize failure
- Heat up to room temperature
- Repair failure
- Cool down to cryogenic level
- Test cable system
- Back in operation

**Required:**

- Fast & homogeneous cooling down

**Relevant a.o.**:

- Localization techniques
- Access to fault site
- Repair methods
- Spare parts




Getting into operation at Asahi cable

# Cooling fast

Future requirements for 3.4 km:

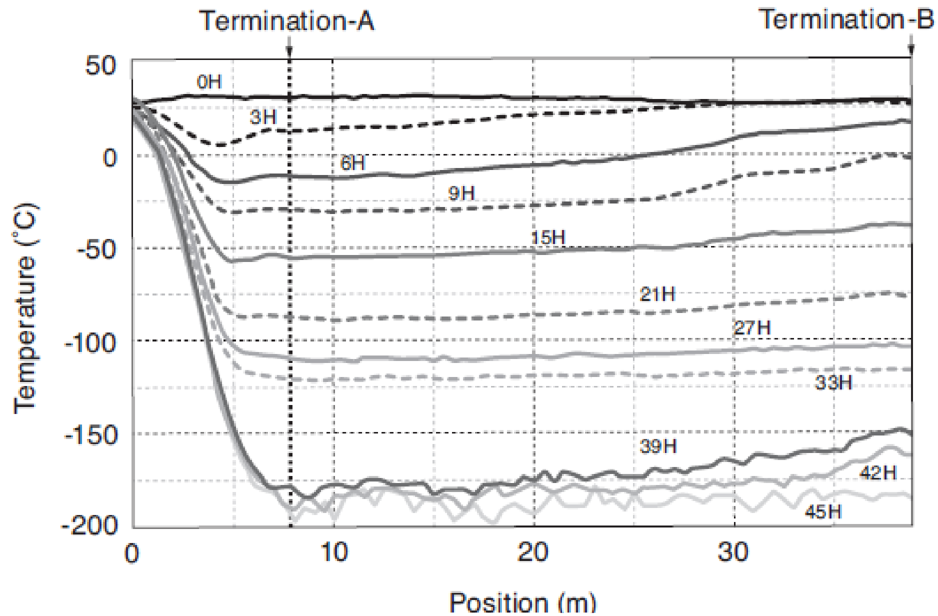
- Few days cooling

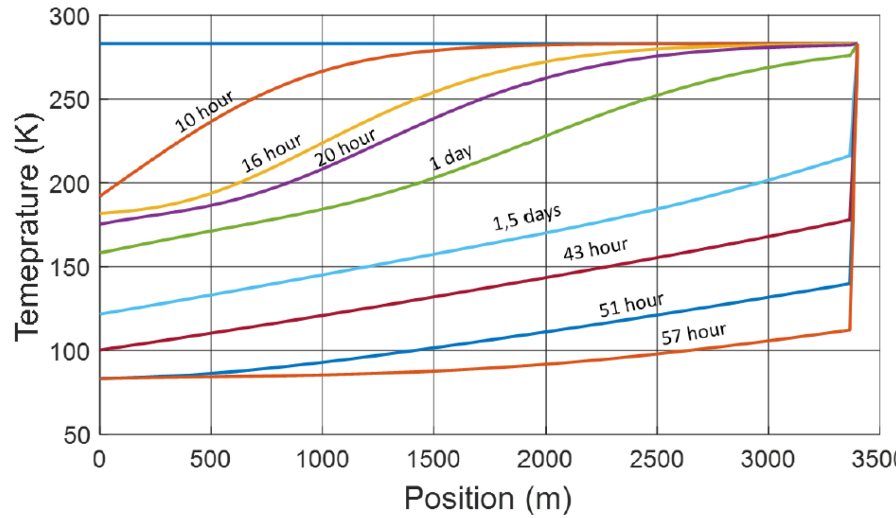
Invention U Twente & IWO

- Secondary cooling channel
- Radiation or convection cooling

Main options: application of

- More efficient high temperature coolant
- Locally enhanced cooling
- Secondary cooling channel as return channel for cooling of radiation shield






**Note: length ratio of ca. 100**

# Conclusions

HTS in the grid

- There are reasons to search for a new transmission technology

HTS Technical aspects

- State of the arts seems adequate for a few kilometre long circuits
- Cooling is new; to be tested and evaluated: efficiency, noise, reliability; seems workable though
- Bringing into operation must become comparable with XLPE, OPC

Testing

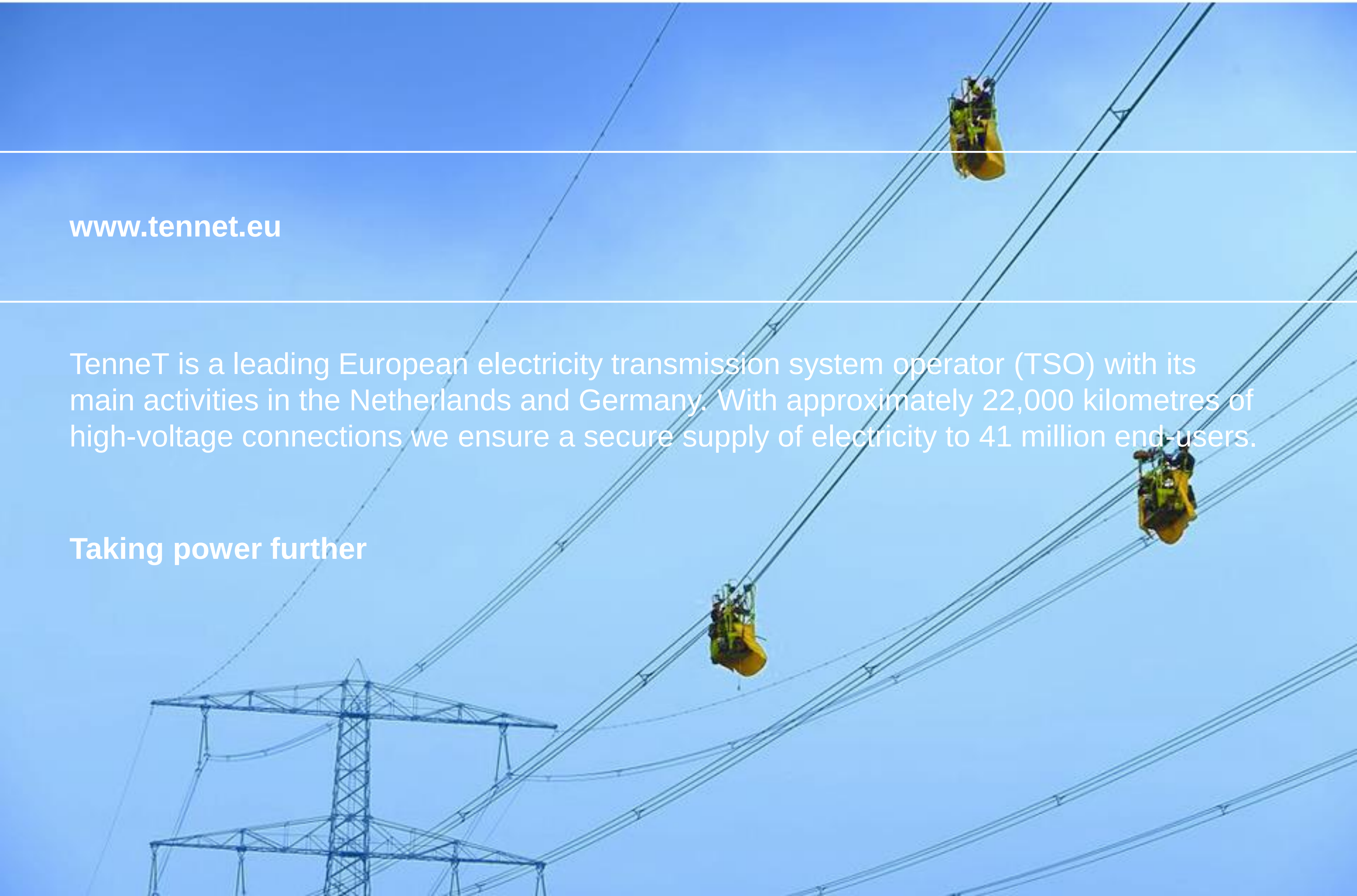
- Some questions about power of law, correspondence to XLPE etc.

HTS Economically

- Not as mature as predicted a few years ago. Exciting, …

# Disclaimer

## Liability and copyright of TenneT



**www.tennet.eu**

TenneT is a leading European electricity transmission system operator (TSO) with its main activities in the Netherlands and Germany. With approximately 22,000 kilometres of high-voltage connections we ensure a secure supply of electricity to 41 million end-users.

**Taking power further**